THE EFFECT OF BURRS ON SLIP CAPACITY IN MULTIPLE BOLT CONNECTIONS

By

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CHAPTER I

INTRODUCTION

1.1 Problem Statement

This research was conducted to assess the effect of burrs on shear capacity in slip-critical connections constructed with multiple bolts. All burrs were formed by punching through a beveled die to control the size of the burrs. An example of typical burrs used in this research is shown in Figure 1. The burrs shown in Figure 1 are approximately 0.090 in. in height. In this study, burrs ranged in height from 0.005 to 0.124 in.

The presence of a burr extending above the surface of a plate will interfere with contact of faying surfaces. This interference may reduce the friction capacity of slip critical connections. Lacking evidence to refute this possibility, members of the Research Council on Structural Connections (RCSC) have taken a conservative approach in their "Specification for Structural Joints Using ASTM A325 or A490 Bolts" [9] in regard to the presence of burrs. Section 3(b) of this specification requires: "Burrs that would prevent solid seating of the connected parts in the snug tight condition shall be removed"; Section 8(c) states: "The snug condition is defined as the tightness that exists when all plies in a joint are in firm contact." The effect of these requirements has been slightly mitigated by statements in the Commentary: "Based upon tests which demonstrate that the slip resistance of joints was unchanged or slightly improved by the presence of burrs, burrs which do not prevent solid seating of the connected parts in the snug tight condition need not be removed," and "in some joints, it may not be possible at snug tight to have contact throughout the faying surface area."

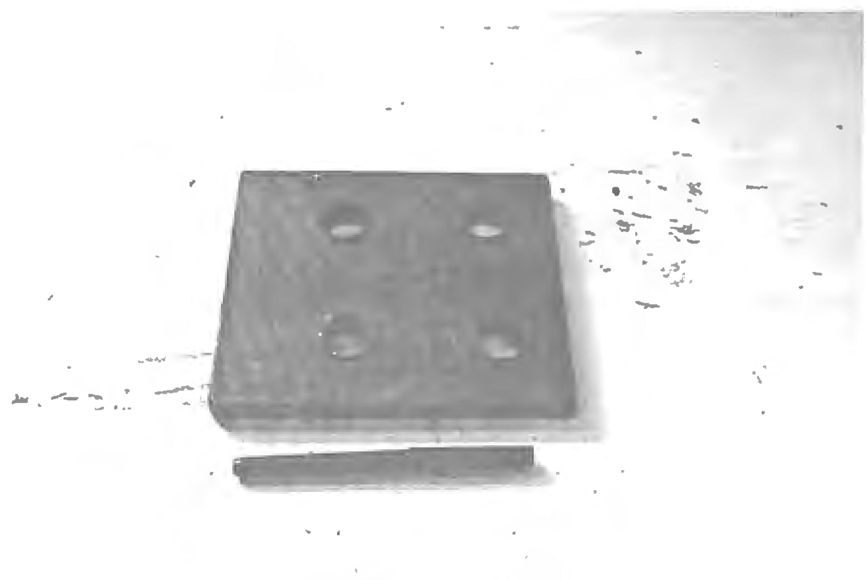


Figure 1. Punched Holes With Large Burrs

If the above quotations are viewed from a common sense point of view, compliance with the Specification would not result in a significant manpower requirement for fabricators using qualified personnel and well maintained equipment. If equipment is in good working condition and is properly operated, burr heights typically fall in the 1/64- to 1/32-in. range. Common sense dictates that a burr of this size is not a threat to connection strength. Surface grinding should only be required if burrs cause an observable seating problem.

If, however, the above quotations are viewed from a strict legalistic point of view, the extension of any material above the plate surface will interfere with "solid seating." Interference exists even if it cannot be seen. This legalistic interpretation has been applied in many cases and effectively results in the requirement that surface grinding take place around every punched hole. Thousands of manhours are spent each year performing what is usually an unnecessary operation.

1.2 Objectives

The objective of this research is to determine if the presence of burrs extending above faying surfaces in multiple bolt slip-critical connections adversely affects the load-carrying capacity of these connections. If the presence of burrs is found not to be detrimental in terms of connection strength, modifications to Sections 3(b) and 8(c) of the RCSC Specification will be proposed.

1.3 Scope

This research program involved the construction and testing of 60 bolted friction connections to measure the effect of burrs on connection shear capacity. Each specimen was built with 3/4-in. diameter A325 bolts. Three different tightening methods were used: 20 specimens were tightened with tension control bolts, 20 were tightened with direct tension indicator washers, and 20 were tightened with the turn-of-nut method. Burr heights ranged from 0.005 to 0.124 in. All specimens were made from A572 Grade 50 steel plate.

CHAPTER II

PREVIOUS WORK

To study the effect of burrs on multiple bolt slip-critical connections, their effects on both slip coefficient and bolt tension must be examined. Even if burrs do not lower the slip coefficient, they may be detrimental to bolt tension in multiple bolt connections. Lower bolt tension results in lower slip capacity.

Slip coefficient has been studied extensively. It is highly dependent on faying surfaces. Many tests have been conducted with faying surfaces described as clean mill scale, and slip coefficients have varied from 0.23 in Reference [14] to 0.46 in Reference [1]. In Reference [4], a slip coefficient mean value of 0.33 from a total of 327 tests by numerous researchers was found. This value was adopted by the RCSC Specification as the appropriate value for clean mill faying surfaces.

Other studies have been conducted to determine the effect of burrs on slip resistance. Polyzois and Yura [8] did work very similar to this study. They used plates with different thicknesses and yield strengths, with burrs ranging from 0 to 1/8 in. in height, to determine if burrs were detrimental to slip resistance. They tested only single bolt connections and ensured proper bolt tension with a hydraulic ram. They recommended additional turns to achieve required bolt tension and concluded that the interlocking of burrs improved the slip resistance of bolted joints.

Vasarhelyi and Chen [13] tested butt splices with main plates that had different thicknesses. This difference in thickness prevented the splice plates from coming into full contact with the thinner main plate. The slip coefficient was reduced for plate thicknesses differing by 1/16 and 1/8 in.

Yura, Hansen, and Frank [15] performed tests on bolted splice connections with undeveloped fillers. The slip coefficient was 0.33 with no filler present, 0.27 when one 1/4-in. filler was present, and 0.18 when three 1/4-in. fillers were present. It was concluded that slip coefficient reduction with a 1/4-in. filler or less was not significant, but only six specimens were tested in the program.

Zwerneman [16] performed tests on single-bolt connections with burrs. It was found that if burrs were 1/16 in or less in height and proper bolt tension was achieved, slip coefficients were adequate.

Bolt tension, like the slip coefficient, is subject to considerable variance. Bolts from the same lot, tightened by the same method, and under the same installation conditons will have appreciable scatter.

One tightening method permitted by the RCSC is the turn-of-nut method. The turn-of-nut method involves tightening a bolt to a snug position and then turning a specified additional amount. At the snug tight condition, tension can vary considerably because elongations are within the elastic range.

To "snug" a bolt, the specification recommends a man's full effort with an ordinary spud wrench. However, the same effort on bolts of different lengths or diameters will cause different snug tension. Also, tension can vary considerably at the snug tight condition because the elongations are within the elastic range. These differences are accounted for in the RCSC by using the same definition of snug for all bolts but varying the amount of rotation required beyond snug for different bolt lengths. Tests have shown that this requirement produces consistent bolt tensions in the inelastic range. Kulak, Fisher, and Struik [4] found that average tension using turn-of-nut was 120% of the minimum tension.

Direct tension indicator, sometimes called load indicating washer, is another acceptable method. A washer with protrusions is placed between the head of the bolt and the gripped material. The bolt is adequately tensioned when the protrusions are flattened a specified amount.

Struik, Oyeledun, and Fisher [12] found that this tension device could reliably achieve minimum bolt tension. However, a much greater rotation was needed to achieve the tension. This was due to the protrusions providing a large deformation capacity as they were flattened. Tests were also performed with out-of-parallel surfaces. This situation is similar to a connection with large burrs. Results were in agreement with results for parallel surfaces; minimum bolt tension was reliably achieved.

Installation conditions also affect bolt tension. Some researchers have found that bolts tested in a laboratory reach a higher tension than bolts installed in the field. This is because bolts in the field often are stored on-site and are unprotected from the environment. When lubricants dry and the bolts begin to rust, more friction is developed between the nut and the bolt. The same tightening effort on a dry, rusted bolt will cause a lower tension than a properly lubricated bolt. In the field, difficulty in tightening a dry bolt is often confused with achieving the proper tension.

Factors that affect bolt tension have been studied extensively. Kulak and Birkemore [5] used ultrasonic measurement to determine the tension in bolts installed in the field rather than in a laboratory. Two different teams tested 317 A325 bolts installed by various methods on various types of construction. All bolts were installed by contractors. The results of the two teams were similar. It was found that the average tension in the field-installed bolts was 1.21 times the minimum specified tension. The standard deviation was 0.05 times the minimum specified tension. Installation by turn-of-nut or by direct tension indicators gave very similar results.

Notch [6] performed tests on bolts used in a multi-story building in which the contractor failed to place hardened washers over 1-1/4-in. A490 bolts. Turn-of-nut tightening method was used. To avoid removing the 15,000 bolts and replacing them with new bolts and washers, tests were performed on a select group of bolts to determine the field tension. An ultrasonic measuring device was used. 118 field-installed A490 bolts were tested; 94 were 1-1/4 in. in diameter. Approximately 50% of the bolts were below the minimum bolt tension. Replacement bolts were reinstalled at these locations. The replacement bolts were installed with washers and the turn-of-nut method. Mean bolt tensions were above the minimum.

It was recommended that additional rotation of the bolts would properly tension the bolts without washers. Further tests were performed and it was found that the bolts could withstand additional turning. A modified turn-of-nut specification was created according to bolt length and diameter. This procedure was followed and proper bolt tensions were achieved.

Rumpf and Fisher [10] performed tests on 170 A325 bolts. Bolts of differing diameters and grips were tensioned by continuous torqueing and incremental torqueing. It was found that there was no difference between continuously torqued and incrementally torqued bolts. Grip size did not affect load-elongation characteristics, if the length of threads under the nut stayed the same.

Piraprez [7] compared a torque method of tightening and a method combining torque and turn-of-nut. The combined method involved tightening to a minimum torque and then turning the nut a specified amount. A total of 204 bolts were tested in the field as well as in the laboratory. One-half of the bolts tightened by torque did not reach the minimum tension. Only 3% of the combined method bolts were below the minimum tension.

Piraprez [7] also compared field-installed to laboratory tested bolts. All bolts were tensioned by the researcher. It was found that more torque was required for the field-installed bolts to reach the same tension as the laboratory bolts. This was attributed to drying of the lubricant in the field.

On the basis of the past work described above, it is expected that the effect of burrs in a multiple bolt slip-critical connection will depend on burr size. Slip coefficients are expected to range between a lower bound value of 0.23 (Reference [14]) to an upper bound value of 0.46 (Reference [1]). It is expected that the direct tension indicator tightening method can reliably achieve proper bolt tension of multiple bolt connections with burrs as indicated by Struik, Oyeledun, and Fisher [12]. Turn-of-nut method is not expected to be able to achieve proper bolt tension reliably. The results of the tension control cannot be predicted, as the only information available is from suppliers.

CHAPTER III

EFFECT OF BURRS IN MULTIPLE BOLT CONNECTIONS

3.1 Specimen Preparation

All specimens were constructed from A572 Grade 50 steel plate. A drawing of a typical specimen is shown in Figure 2. The steel was transported by truck to the testing laboratory in 20-ft long by 6-in. wide rolled bars. A bandsaw was used to cut 7-in. long pieces from the bar. This produced 6-in. x 5/8-in. x 7-in. plates with rolled edges along the 7-in. sides and cut edges along the 6-in. sides.

Cleaning involved grinding on the cut edges of the plates to dull the sharp edge. Care was taken not to grind the surface of the plates. Each of the plates was then numbered with 1/4-in. number punches along one of the cut edges. A pattern was made to mark the holes with a small punch. The pattern was 1/2-in. plywood cut to the same size as the specimen. It was positioned on the lower left corner, according to the punched numbers, of each plate. This provided good alignment when the plates were bolted together.

The plates were then punched using a 300-kip capacity universal test machine outfitted with a 15/16-in. punch and a 1-in. die. This resulted in oversized holes for the 3/4-in. bolts. A photograph of the setup is shown in Figure 3.

Burr size was controlled by the condition of the cutting edge on the die. Four different burr sizes were tested in this study. When the die was used as-received, it produced thin, irregular shaped burrs ranging in height from 0.005 to 0.034 in. Larger burrs were produced by punching holes through a die with a beveled cutting edge. A 1/16-in. wide, 45° bevel cut around the inside diameter of the die caused burrs

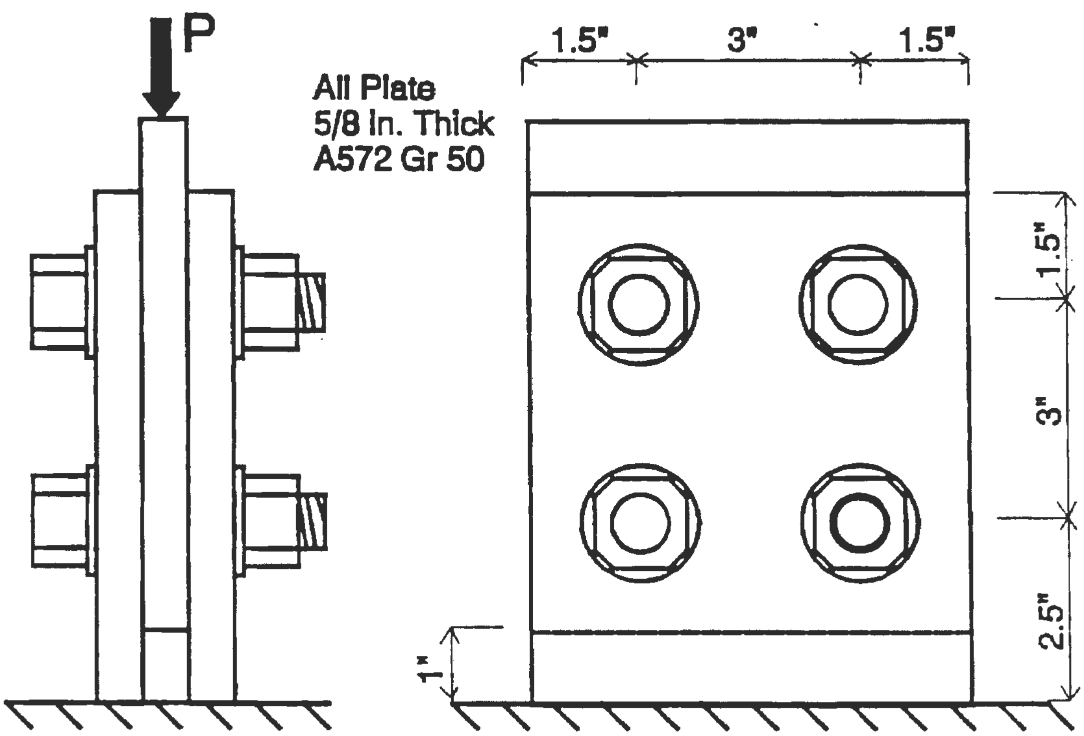


Figure 2. Four-Bolt Specimen for Slip Coefficient Tests

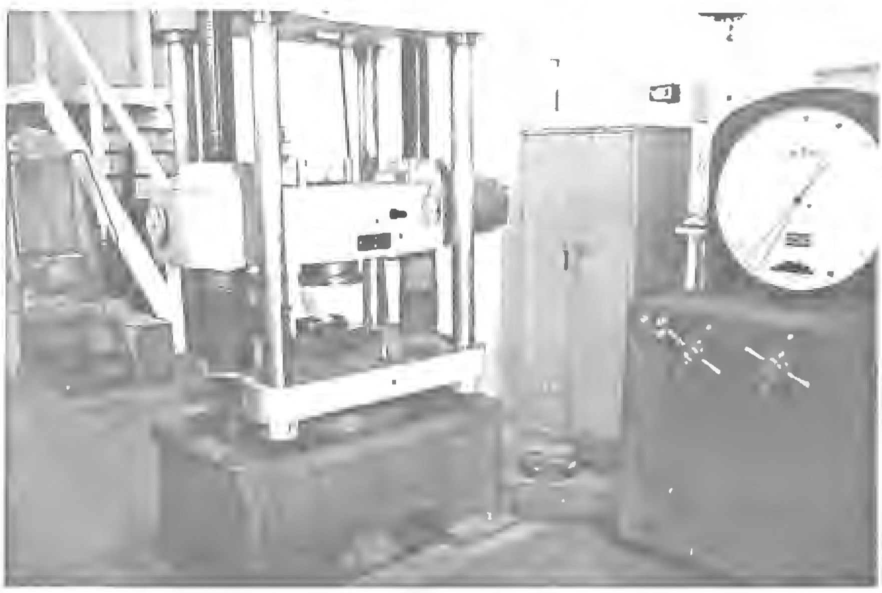


Figure 3. Hole-Punching Equipment

approximately 1/32 in. in height to form completely around the hole. A 1/16-in. wide, 30° bevel produced burrs that were approximately 1/16 in. in height, and a 1/8-in. wide, 30° bevel produced burrs slightly less than 1/8 in.

Fifteen specimens were prepared for each of the four burr heights. The 15 specimens for each burr height were comprised of 5 tension control specimens, 5 load indicating washer specimens, and 5 turn-of-nut specimens. This resulted in a total of 60 specimens.

Specimens were cleaned by dipping them into a liquid solvent and drying with a dry rag. This removed any cutting oil from the plates, which would reduce friction between faying surfaces.

Burr heights were measured using a dial indicator as shown in Figure 4. Maximum burr height was located by moving the dial indicator around the hole. When the maximum height was determined, this value was recorded and burr heights were measured and recorded for positions 90, 180, and 270° from the maximum burr. The burr heights were reasonably consistent in terms of size and shape around the hole. There was no tendency to have a large burr on one side of the hole and no burr on the other side.

The plates were then bolted together. To keep the top and bottom surfaces of the specimens parallel while bolts were tightened, plates were mounted in the jig shown in Figure 5. The center plate is forced against the top of the jig by two bottom screws. Outside plates are forced against the bottom of the jig by four top screws. This prevents the plates from rotating relative to each other. It also makes the top and bottom surfaces of the plates parallel. This is important because these will be the loading surfaces for slip load measurements. The jig also causes each bolt to be near the top of the oversized hole in the outside plates and near the bottom of the hole in the inside plate. This arrangement allows the inside plate to slide through the outside plates during loading without bearing on the bolt.

To determine the slip coefficient from shear tests, it is necessary to know the contact force between the plates. This contact force is equal to the tension. For

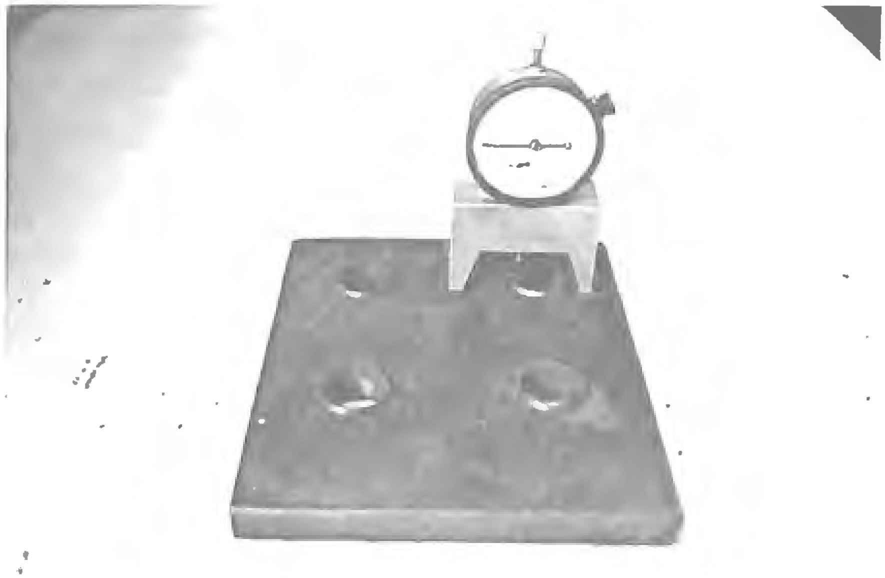


Figure 4. Measurement of Burr Height

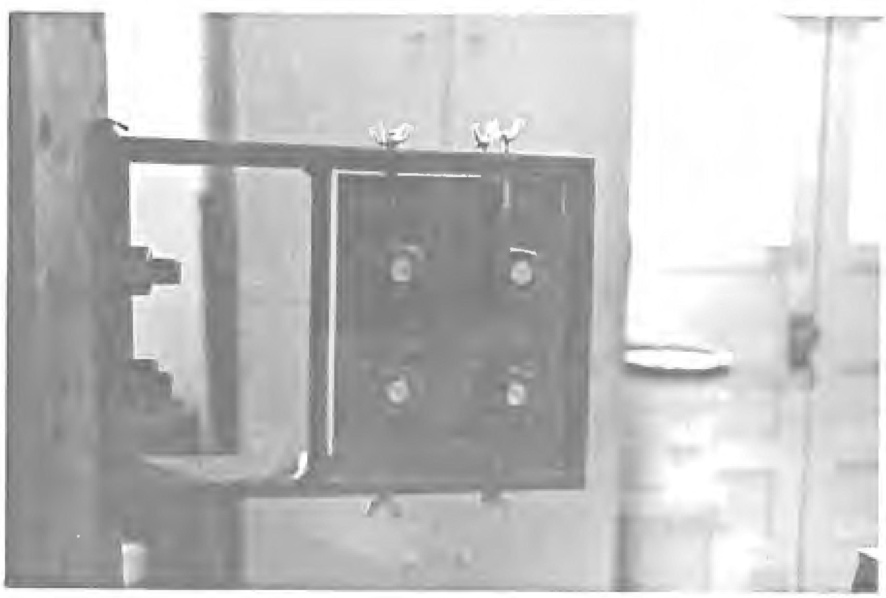


Figure 5. Photograph of Alignment Jig

tension control bolts, it was assumed that bolt tension was equal to average tension measured in the Skidmore-Wilhelm for five bolts. These bolts were taken from the same group of bolts used in the specimens.

For all installation techniques except the tension control bolts, bolt tension was determined from the load-elongation relationship for the bolts. The load-elongation relationship for the hex-head bolts is based on measurements made from three bolts tensioned in the Skidmore-Wilhelm. These bolts were of the same diameter, length, grade, and grip as those to be mounted in the specimens. Prior to testing, gage marks were made with a punch on the top and bottom of all bolts. Changes in bolt length during tightening were measured using a 1/10,000-in. dial gage mounted in a frame as shown in Figure 6.

The results of the load-elongation measurements are shown in Figure 7. Data for each of the three bolts are plotted with a different symbol. A first-order curve was fit to the initial elastic portion of the data and a second-order curve was fit to the data above the yield point. Equations for both curves are given in the figure.

The RCSC Specification requires nuts to be turned to the snug-tight condition prior to being fully tensioned. The Specification defines snug as the tightness that exists when all plies in a joint are in firm contact, then continues by stating that this tightness may be attained by a few impacts of an impact wrench or the full effort of a man using an ordinary spud wrench. Previous research has defined snug bolt tension as 5 kips [12], 8 kips [2,3,10], and 10 kips [11].

Zwerneman [16] found the average torque required to produce 8 kips tension in five bolts. This torque averaged 105 ft-lbs as measured with a 150-ft-lb torque wrench. A torque of 105 ft-lbs was used to snug all bolts in this study. Bolt tension at 105 ft-lbs is plotted versus burr height in Figure 8. The decline in tension with increasing burr height is small and the scatter increases slightly with burr height.

In the test specimens, initial bolt length was measured when the three plates and the bolt had been assembled and the bolt was hand tight. All bolts were snugged using a torque wrench set at 105 ft-lbs. The average snug tension among the load indicating

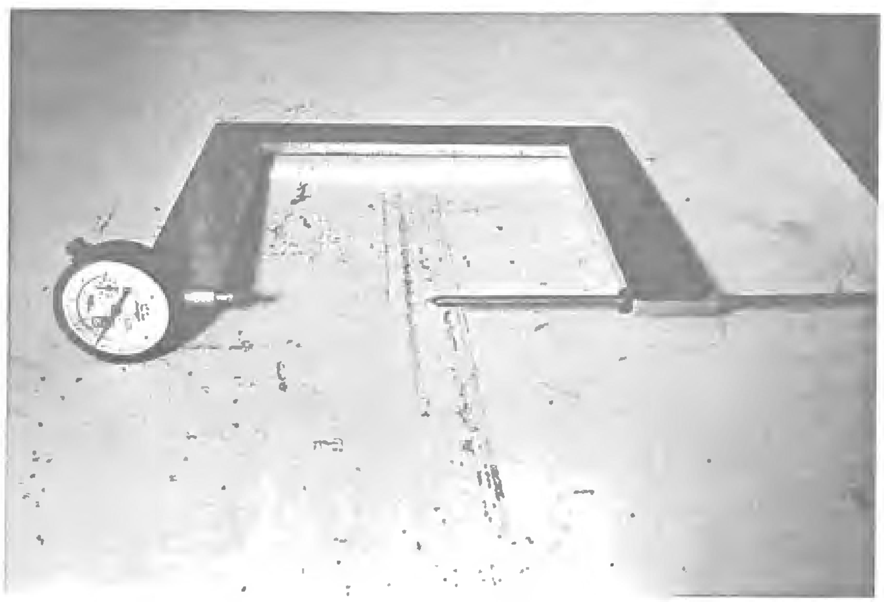


Figure 6. Instrument Used for Bolt Elongation Measurements

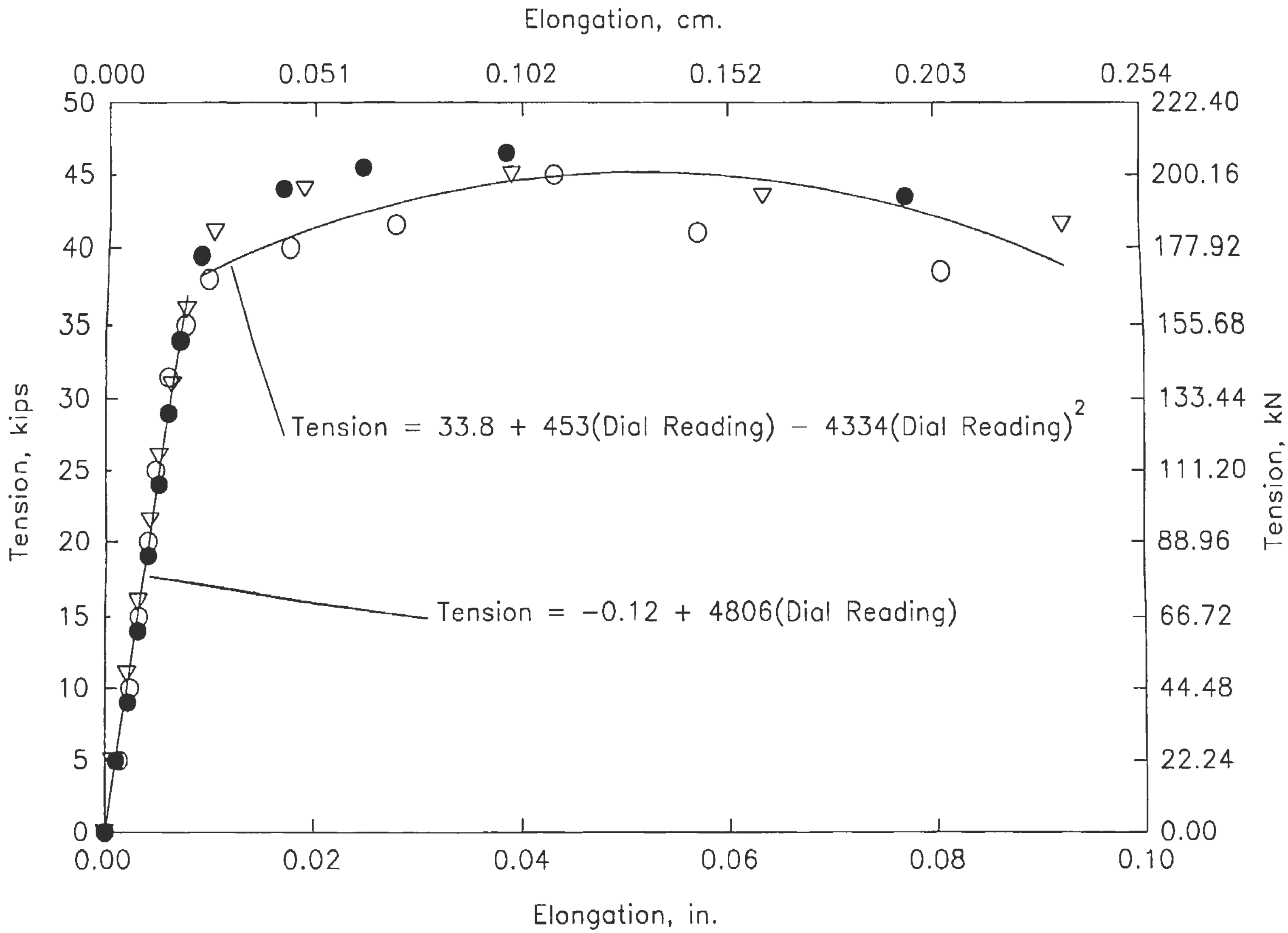


Figure 7. Bolt Tension Versus Elongation

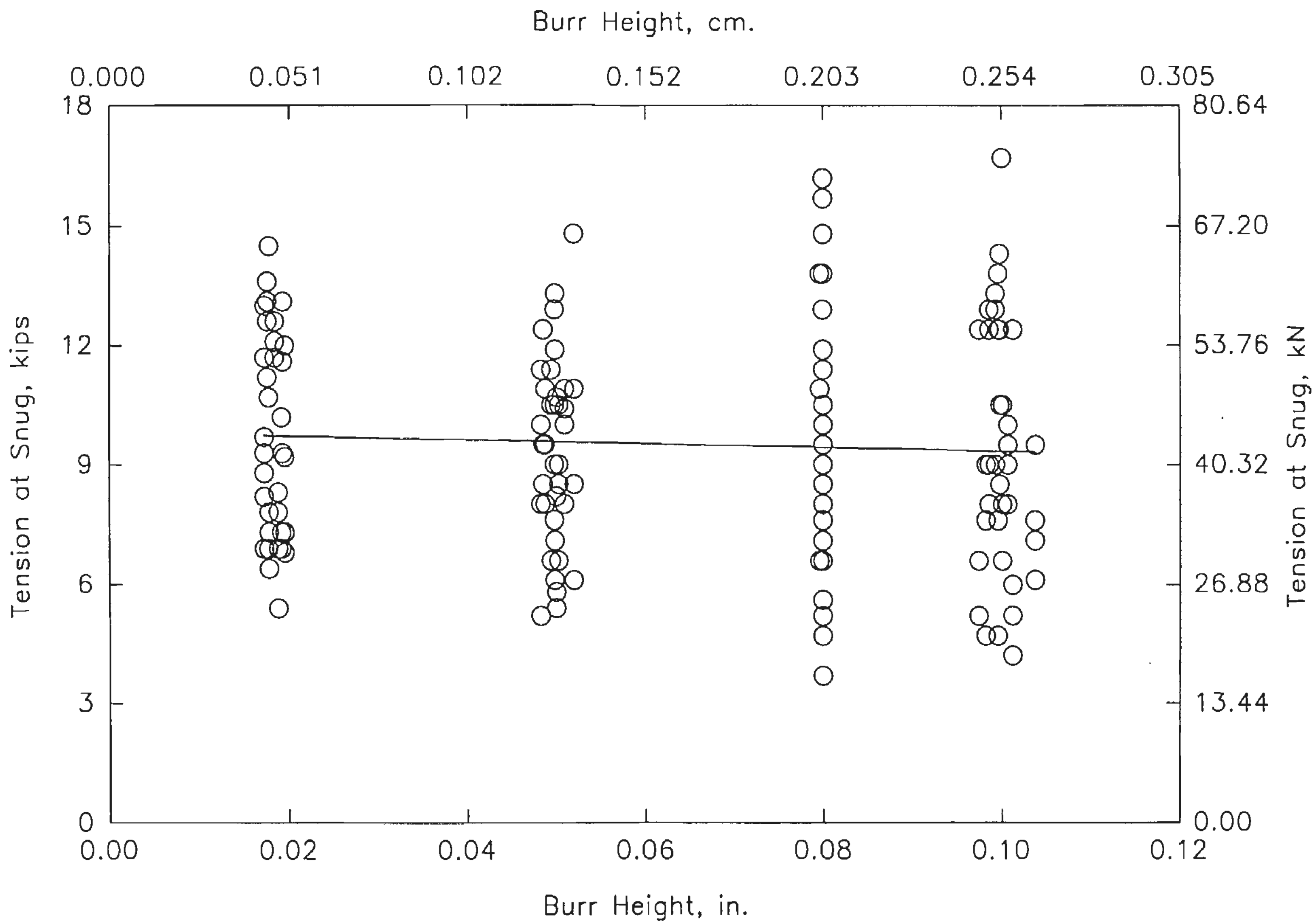


Figure 8. Bolt Tension at Snug Versus Burr Height

washer and turn-of-nut bolts in this study is 9.55 kips. Snug tension for the tension control bolts is not known.

Bolts were tightened by turning each bolt 1/4 turn sequentially, starting with the top left, moving to the bottom right, then to the top right, and ending with the bottom left. Elongations were measured for all bolts after each 1/4 rotation of each bolt. For example, the top left bolt was tightened 1/4 turn, all bolt elongations were measured, then the bottom right bolt was tightened 1/4 turn, and all bolt elongations were measured, etc. Actual tension was determined from the fitted load-elongation curves on the basis of the measured change in length after each 1/4 turn.

This procedure often caused one bolt to lose tension as other bolts were being tightened. When a bolt was tightened, it flattened its corresponding burr. It also slightly flattened the other burrs. This allowed previously tightened bolts to relax and lose tension. After burrs were compressed and faying surfaces brought in contact, bolt tensions did not drop as before and were more uniform among the four bolts. Tightening was continued until all four bolts in the specimen had a tension above the minimum value recommended by the RCSC for bolts of this length and diameter, 28 kips. Final tension among the four bolts was approximately the same.

The data were recorded differently for each of the tightening methods. Tension control data sheets consisted of only a checkmark if the nut completed the 1/4 turn without the splined end twisting off and an "x" if the end twisted off before the 1/4 turn was completed.

Load indicating washer data sheets consisted of bolt elongation in inches after each 1/4 turn and the tension developed due to this elongation. An "x" was recorded when a 0.015-in. feeler gage would no longer fit between three of the five protrusions around the washer. This was only recorded once per bolt, because once these were flattened, they remained flattened.

After some of the direct tension indicators were flattened, rotations of other bolts caused the tension to drop in previously tightened bolts. This resulted in flattened direct tension indicators for bolts with a tension that had dropped below the 28-kip minimum. Further rotations were necessary to properly tension these bolts. Table 1 shows the average number of turns required for minimum tension after the direct tension indicators had been flattened.

Table 1 shows that the number of turns required after the direct tension indicators were flattened increased slightly with burr height. However, the largest burr size required only 1/6 turn after flattening. This amount is small and would not have a significant effect on bolt tension.

TABLE 1

NUMBER OF TURNS REQUIRED FOR MINIMUM TENSION AFTER DIRECT TENSION INDICATORS HAD BEEN FLATTENED

Average Burr Size, in.	Number of Turns
0.0177	0.0875
0.0496	0.1250
0.0792	0.1125
0.0993	0.1625

3.2 Test Procedure

All specimens were tested in a 300-kip capacity universal test machine. Load was applied at a rate of approximately 10 kips per minute. Deformation was measured using a direct current differential transformer (DCDT) mounted between the loading table and the crosshead. An x-y recorder was used to maintain a continuous record of load versus deformation. A photograph of the apparatus is provided in Figure 9.

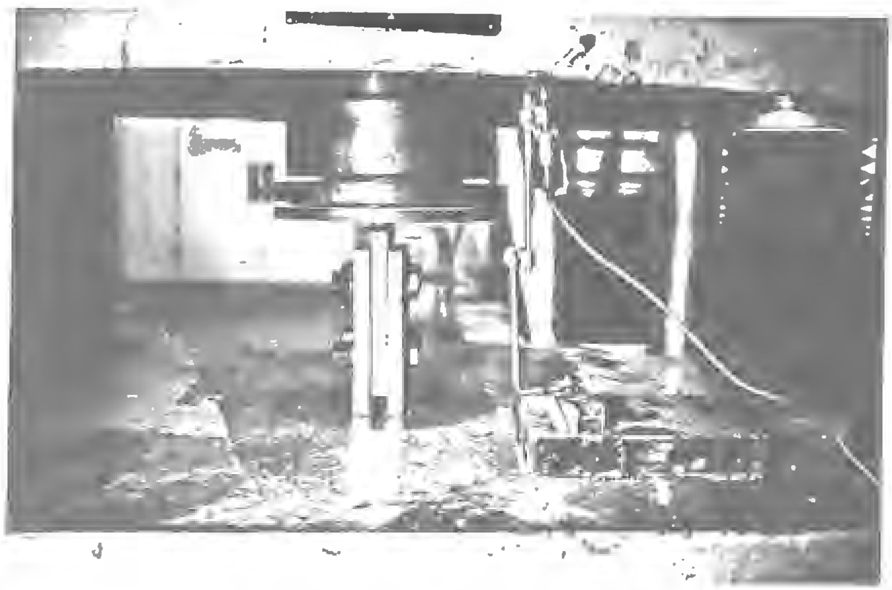


Figure 9. Apparatus for Slip Tests

3.3 Results and Discussion

Plots of load versus deformation for two different specimens are shown in Figures 10 and 11. Note that the deformation scale is set at zero under a load of 2,500 lbs. Since deformations were measured between the load table and the crosshead instead of directly on the specimen, this preload was necessary to eliminate most of the nonlinear behavior associated with seating the specimen. The point of slip is circled and is written on both plots. In Figure 10, the slip load is easily identified. In Figure 11, the relevant point of slip is not as clear. To establish the point of slip as objectively as possible, slip load was defined as the maximum load prior to any decrease in load with increasing deformation. No minimum limit was set on the amount of decrease in load or increase in deformation.

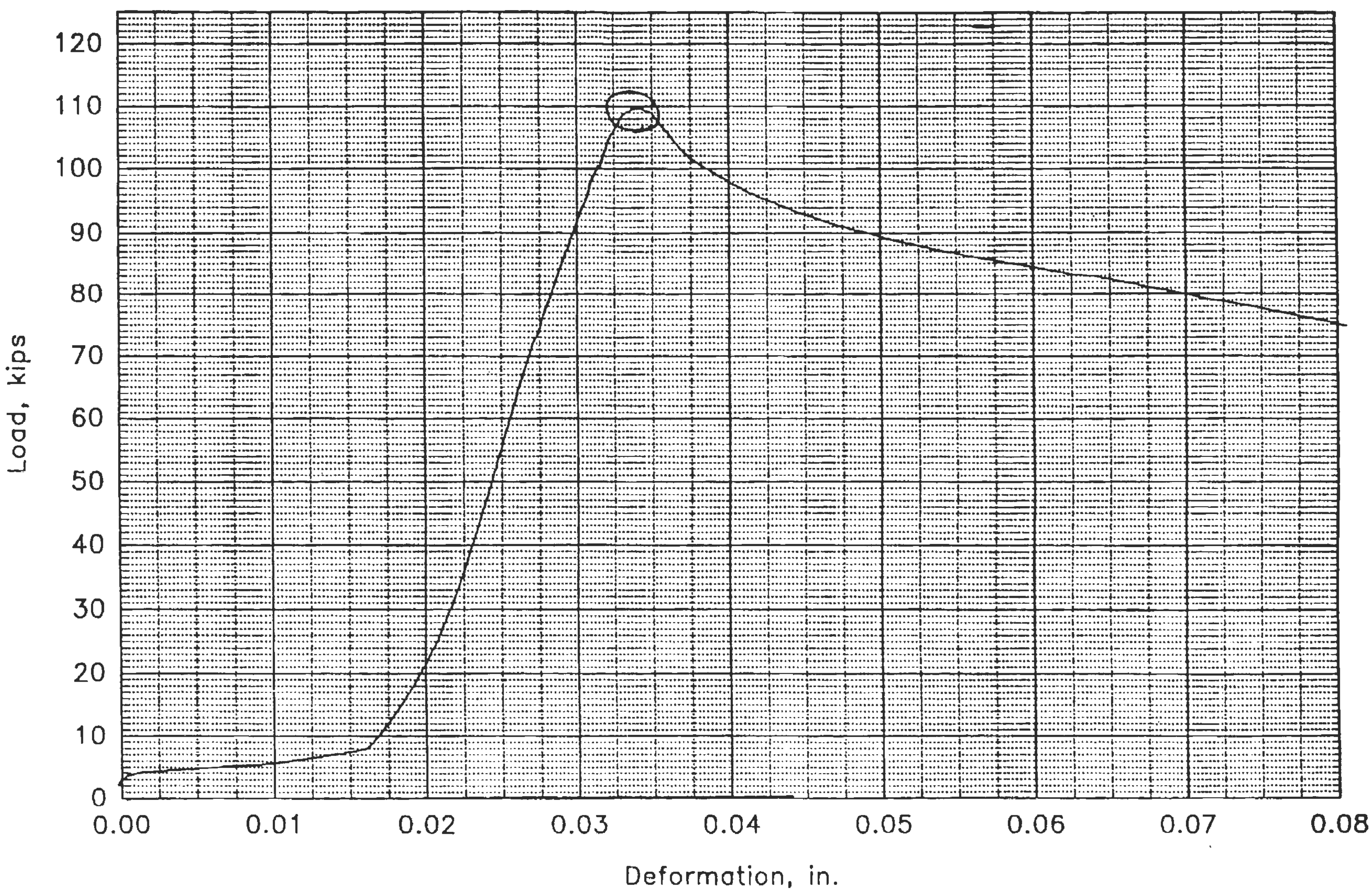
Slip coefficients were calculated as shown below:

$$k_s = P/(mT)$$

where k_s is the slip coefficient, P is the slip load, T is the sum of bolt tension from the four bolts, and m is the number of slip planes. Slip load was taken directly from load-deformation plots, bolt tension was determined on the basis of measured changes in length, and the number of slip planes was always two.

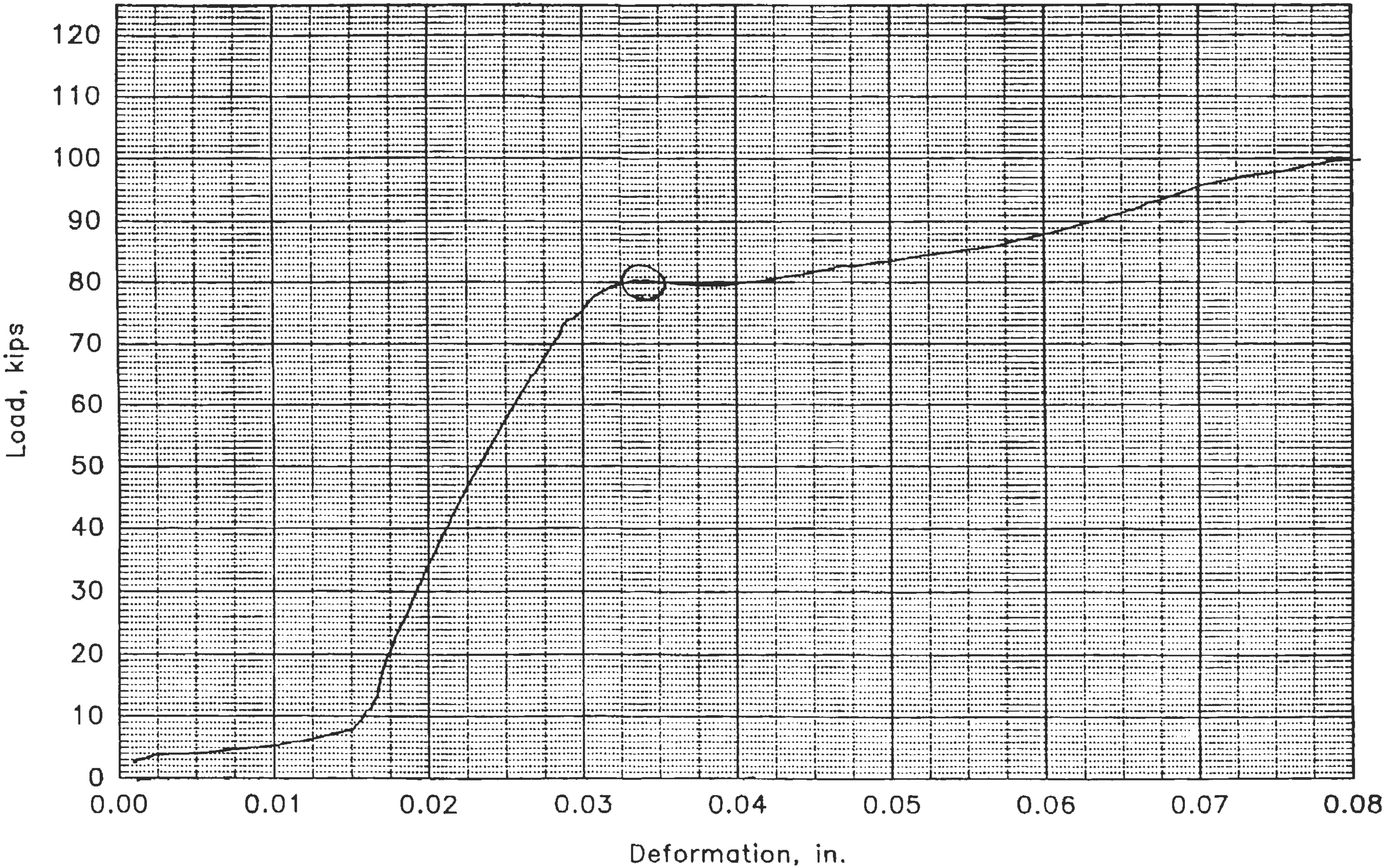
All slip coefficient versus burr height data are listed in Table 2. Burr heights are the average height for the twelve holes punched for each specimen. All data are plotted in Figure 12, with a first-order regression line and the 99% confidence limits for the regression. Some burr heights in the 1/16-in. range were not measured due to a procedural error. In order to include these specimens in the figures, burr heights used were the average of the remaining 1/16-in. specimens. This did not affect the slip coefficient for these specimens.

In Figure 13, the data from Figure 12 are replotted with a second-order regression line. The slip coefficient increases with increasing burr size until the burr height is about 0.05 in. and then decreases. The reason for this decrease is that small burrs cause interlocking of the contact surfaces without losing contact between the surfaces.



Specimen No. 24 Plates No. 1334, 1335, 1336 Max. Load 108,500

Figure 10. Load Versus Deformation, Specimen No. 24



Specimen No. 50 Plates No. 1412, 1413, 1414 Max. Load 80,500

Figure 11. Load Versus Deformation, Specimen No. 50

TABLE 2

SHEAR CAPACITY IN FRICTION CONNECTIONS

Specimen Number	Bolt Tension Sum, kips	Slip Load, kips	Slip Coefficient	Burr Height, in.
1	129.6	81.0	0.312	0.0149
2	129.6	81.5	0.314	0.0158
3	129.6	70.0	0.270	0.0150
4	129.6	76.0	0.293	0.0169
5	129.6	71.0	0.273	0.0209
6	129.1	87.0	0.336	0.0173
7	123.8	87.0	0.351	0.0196
8	156.9	118.5	0.377	0.0188
9	157.1	87.5	0.278	0.0173
10	128.3	70.5	0.274	0.0184
11	152.7	93.0	0.304	0.0178
12	143.1	98.5	0.344	0.0193
13	147.6	99.5	0.337	0.0192
14	150.5	94.5	0.313	0.0176
15	140.1	88.5	0.315	0.0178
16	129.6	83.0	0.320	0.0495
17	129.6	86.5	0.333	0.0511
18	129.6	85.0	0.327	0.0483
19	129.6	93.5	0.360	0.0487
20	129.6	86.0	0.331	0.0494
21	154.6	132.0	0.426	0.0499
22	152.8	116.0	0.379	0.0493
23	135.8	105.0	0.386	0.0498
24	133.0	108.5	0.407	0.0484
25	137.5	63.0	0.229	0.0508
26	143.9	123.5	0.375	0.0487
28	156.5	125.0	0.399	0.0502
29	156.6	112.0	0.429	0.0482
27	157.3	118.0	0.357	0.0497
30	152.5	119.5	0.391	0.0519
31	129.6	64.0	0.246	0.0782
32	129.6	70.5	0.271	0.0769
33	129.6	68.0	0.262	0.0799
34	129.6	76.5	0.295	0.0801
35	129.6	80.0	0.308	0.0805
36	131.6	79.0	0.300	0.0796
37	129.7	79.5	0.306	*
38	140.3	89.5	0.318	*
39	146.3	77.5	0.264	*
40	129.7	93.0	0.358	*
41	124.6	73.0	0.292	*

TABLE 2. (Continued)

Specimen Number	Bolt Tension Sum, kips	Slip Load, kips	Slip Coefficient	Burr Height, in.
42	151.7	92.5	0.304	*
43	150.8	91.0	0.301	*
44	145.9	93.0	0.318	*
45	148.7	97.5	0.327	*
46	129.6	64.5	0.248	0.0959
47	129.6	73.0	0.281	0.0103
48	129.6	63.5	0.244	0.0970
49	129.6	72.5	0.279	0.0968
50	129.6	80.5	0.310	0.0978
51	128.3	66.0	0.257	0.0104
52	157.3	89.5	0.284	0.0101
53	125.4	77.5	0.309	0.0974
54	144.9	81.5	0.281	0.0998
55	156.4	93.0	0.297	0.0982
56	149.6	88.0	0.294	0.0100
57	153.9	101.0	0.328	0.0996
58	138.7	82.5	0.297	0.0986
59	135.8	101.0	0.371	0.0101
60	150.3	96.5	0.321	0.0993

*Burr height was not measured for the specimen.

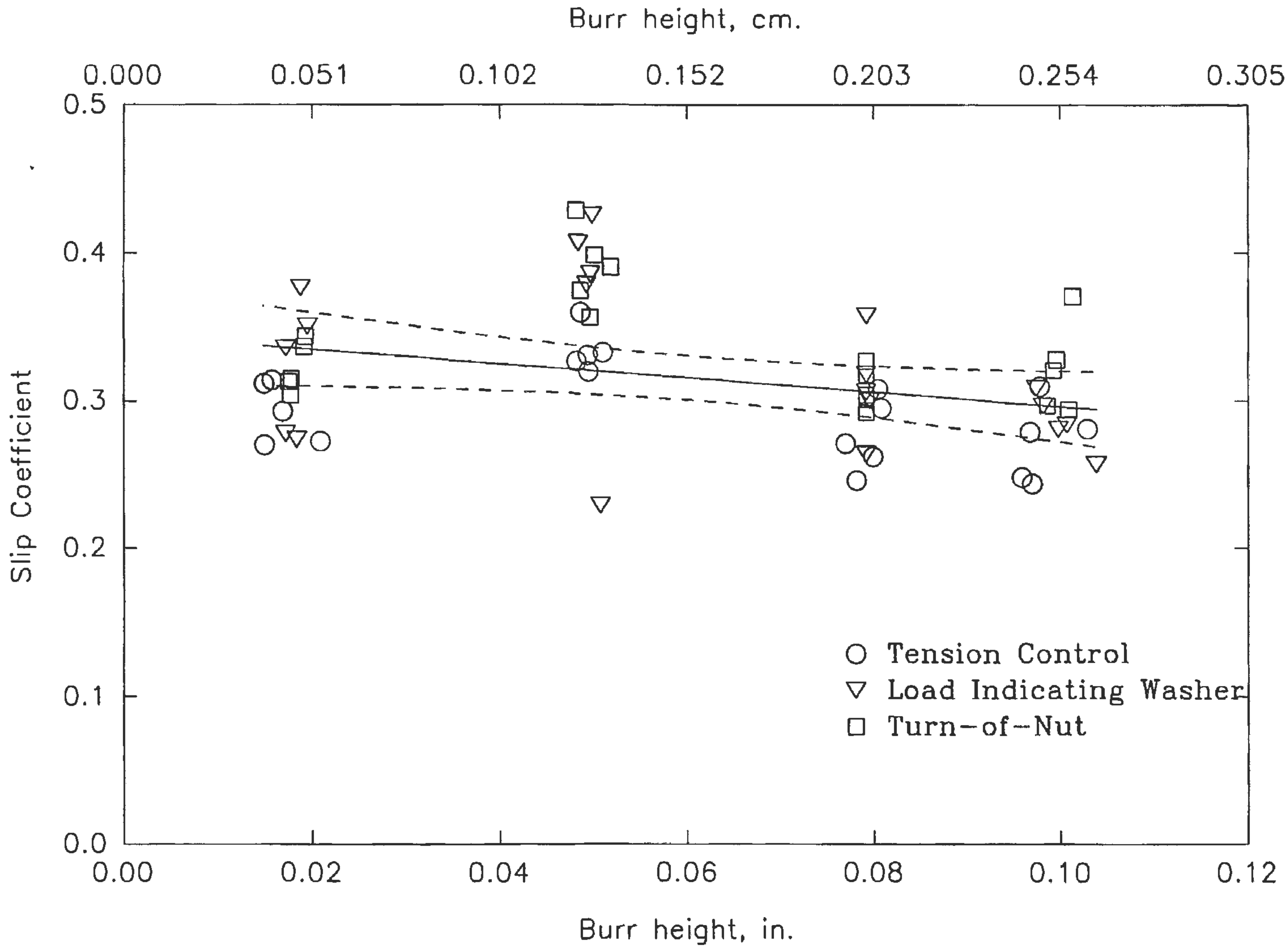


Figure 12. Slip Coefficient Versus Burr Height With
99% Confidence Limits for All Data

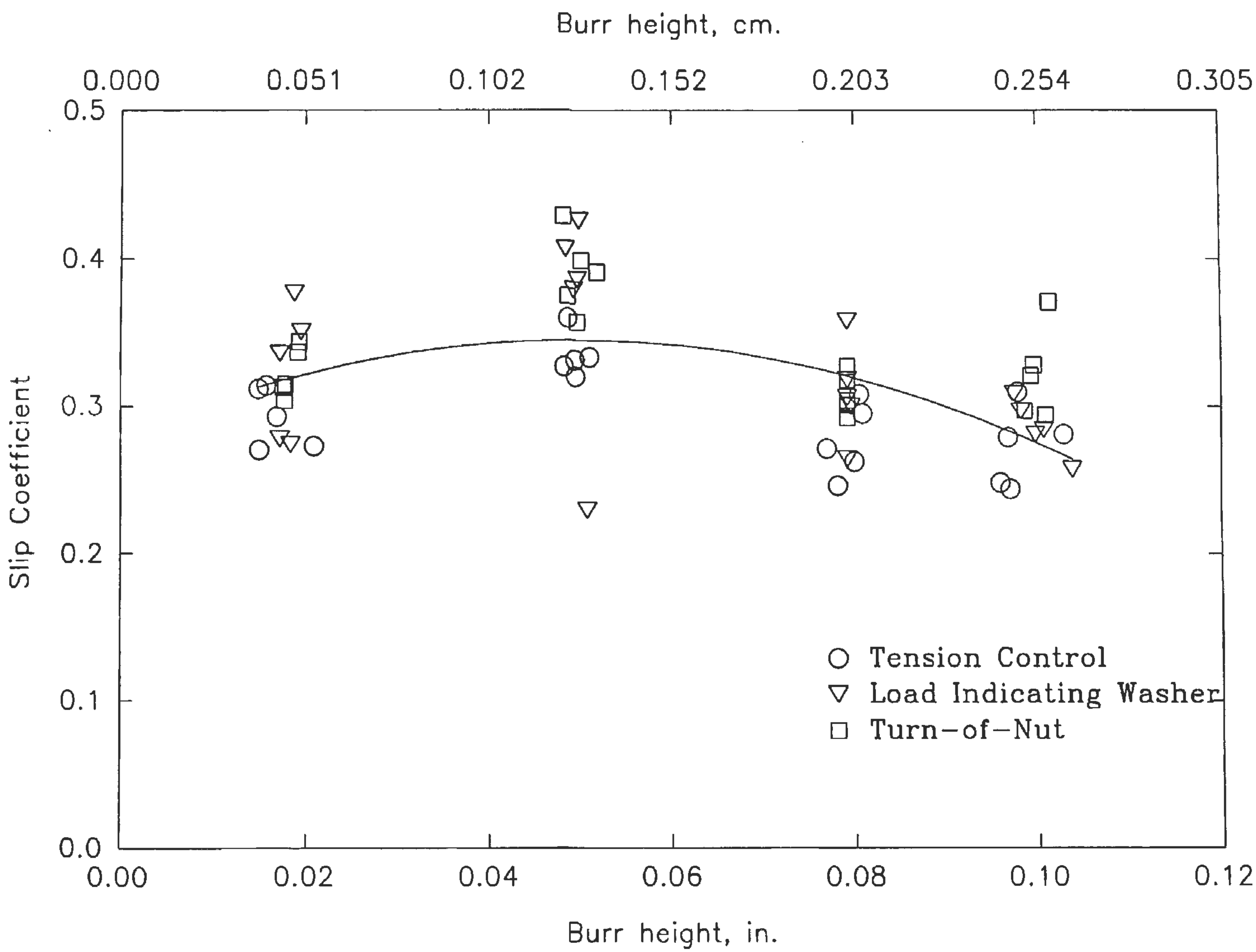


Figure 13. Slip Coefficient Versus Burr Height With Second-Order Regression

Larger burrs also interlock but cause a large amount of surface contact to be lost, which lowers the slip coefficient.

Figure 14 is a histogram of slip coefficient for all specimens. Reference [4] is used as the basis for the RCSC specifications related to slip coefficients, and lists a mean of 0.33 and a standard deviation of 0.07. The present study has approximately the same mean with a smaller standard deviation, 0.046.

Figures 15 through 20 show slip coefficients according to the three tightening methods. Each tightening method is shown with a regression line for all specimens identical to the one in Figure 12 and then with a second-order regression line specific to that data. These individual data sets show the same variation of slip coefficient with burr height as the entire set of data. Slip coefficient is not lowered by burrs smaller than 1/16 in., regardless of the tightening method used.

It can also be seen in Figures 12, 13, and 15 that tension control specimens had slightly lower slip coefficients than the other methods. This is because the bolt tension in the tension control specimens may have been lower than the other two tightening methods, in which tightening continued until all four bolts had a minimum of 28 kips. The reason tension control may have had lower bolt tension is because after the splined end of one of the bolts was twisted off and the bolt tensioned, other bolts were tightened which flattened the burrs and allowed the previously tightened bolts to lose tension.

Table 3 presents the average number of turns required to reach minimum bolt tension for each of the three tightening methods. It can be seen that more rotation is required as burr size increases. This is because some rotation is required to flatten the burrs before plate surfaces come into contact, after which further rotation allows proper bolt tension.

Table 3 shows that tension control bolts required more rotation than turn-of-nut. This may be due to tension control bolts reaching a higher initial tension. All five tension control bolts tested in the Skidmore-Wilhelm were snugged, tightened 1/4 turn,

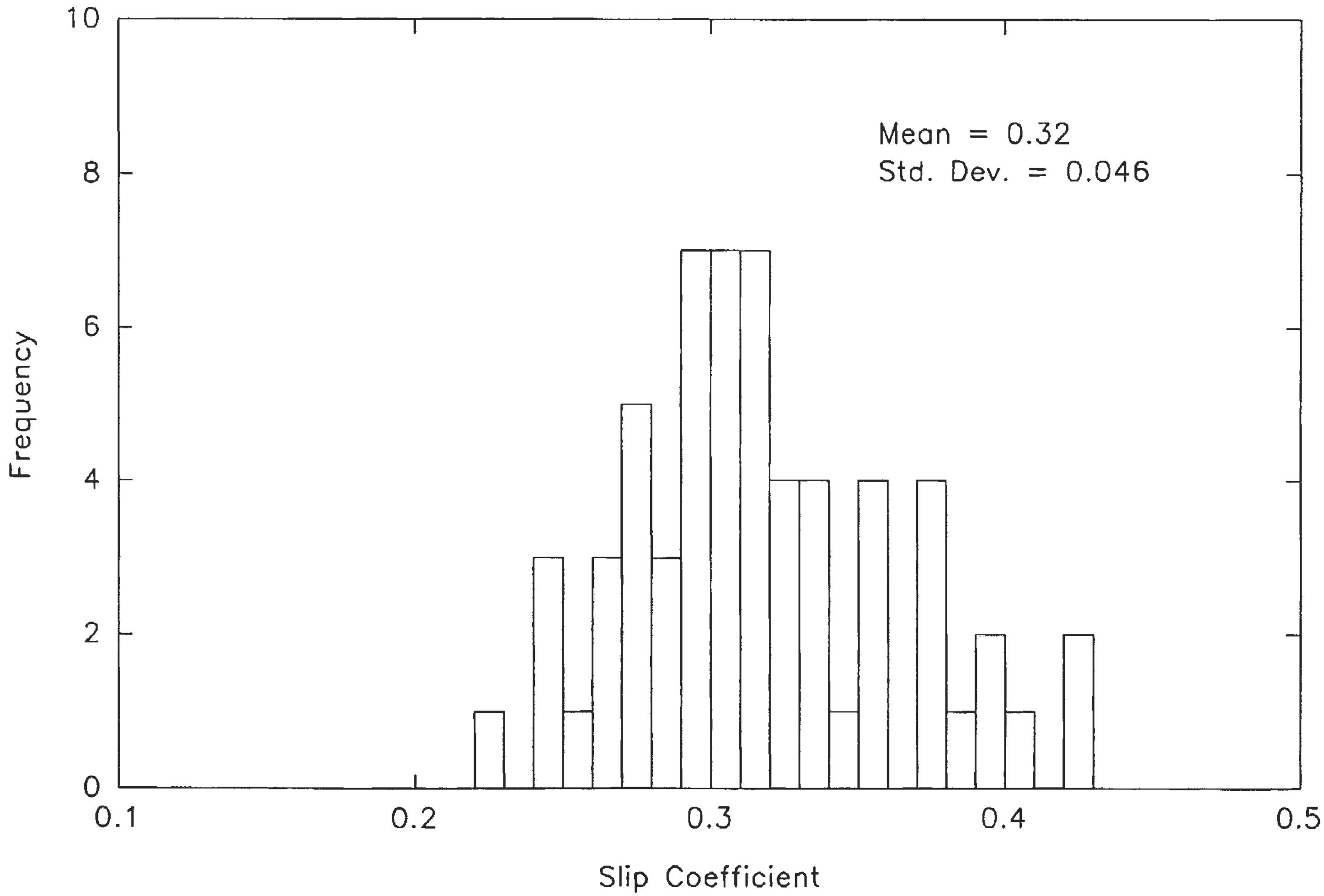


Figure 14. Histogram of Slip Coefficient

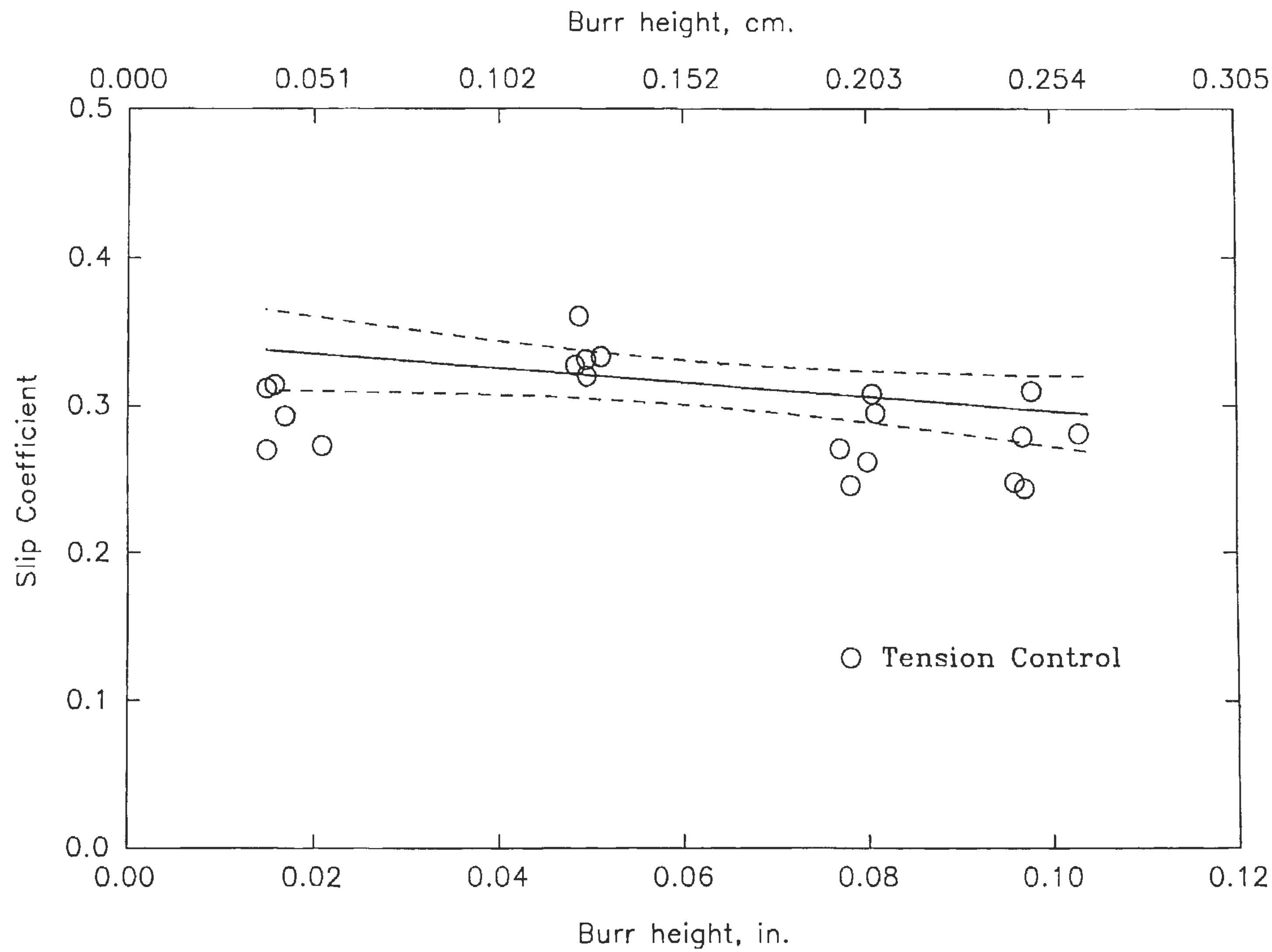


Figure 15. Slip Coefficient Versus Burr Height for Tension Control Data
With 99% Confidence Limits for All Data

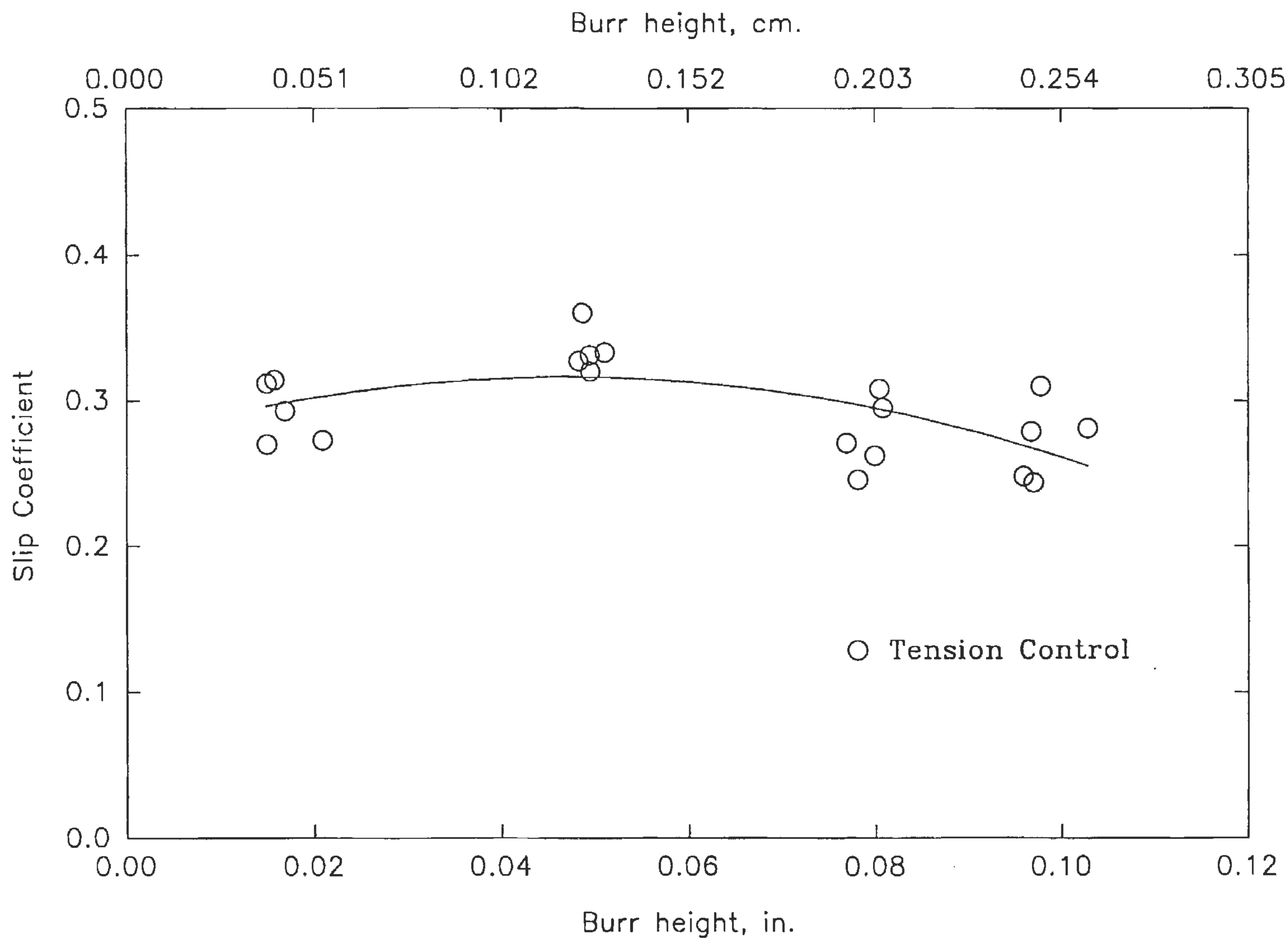


Figure 16. Slip Coefficient Versus Burr Height for Tension Control Data With Second-Order Regression

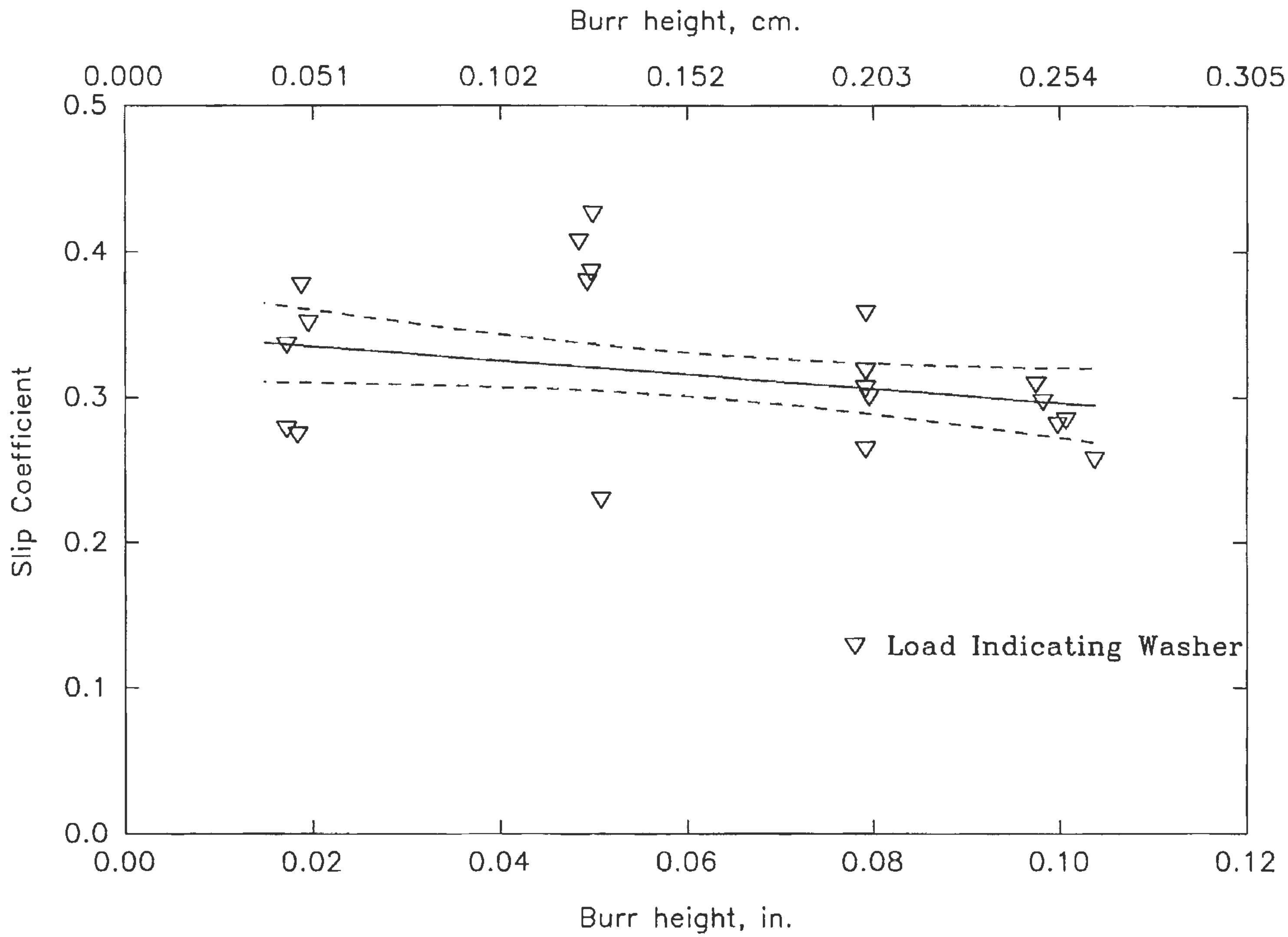


Figure 17. Slip Coefficient Versus Burr Height for Load Indicating Washer Data
With 99% Confidence Limits for All Data

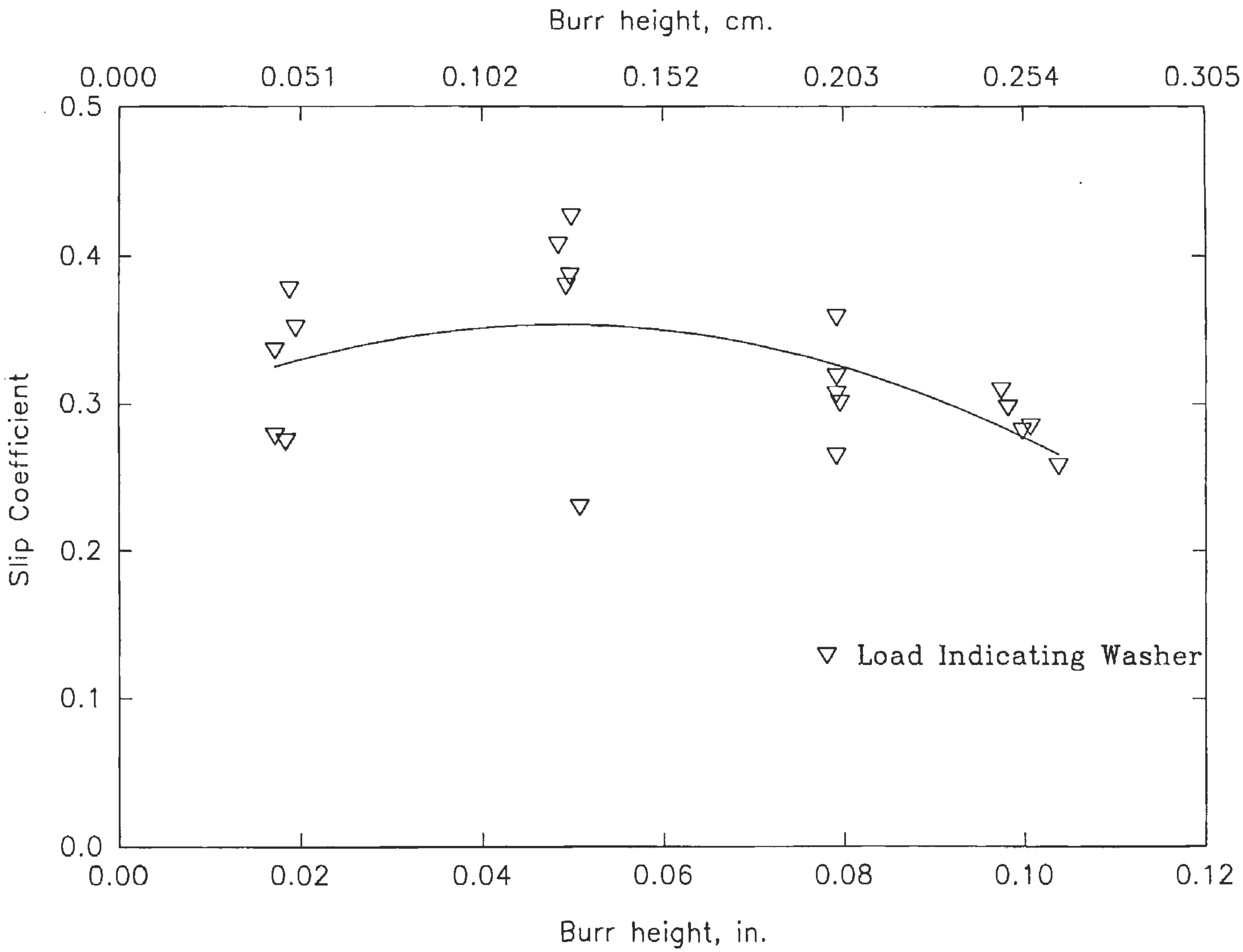


Figure 18. Slip Coefficient Versus Burr Height for Load Indicating Washer Data With Second-Order Regression

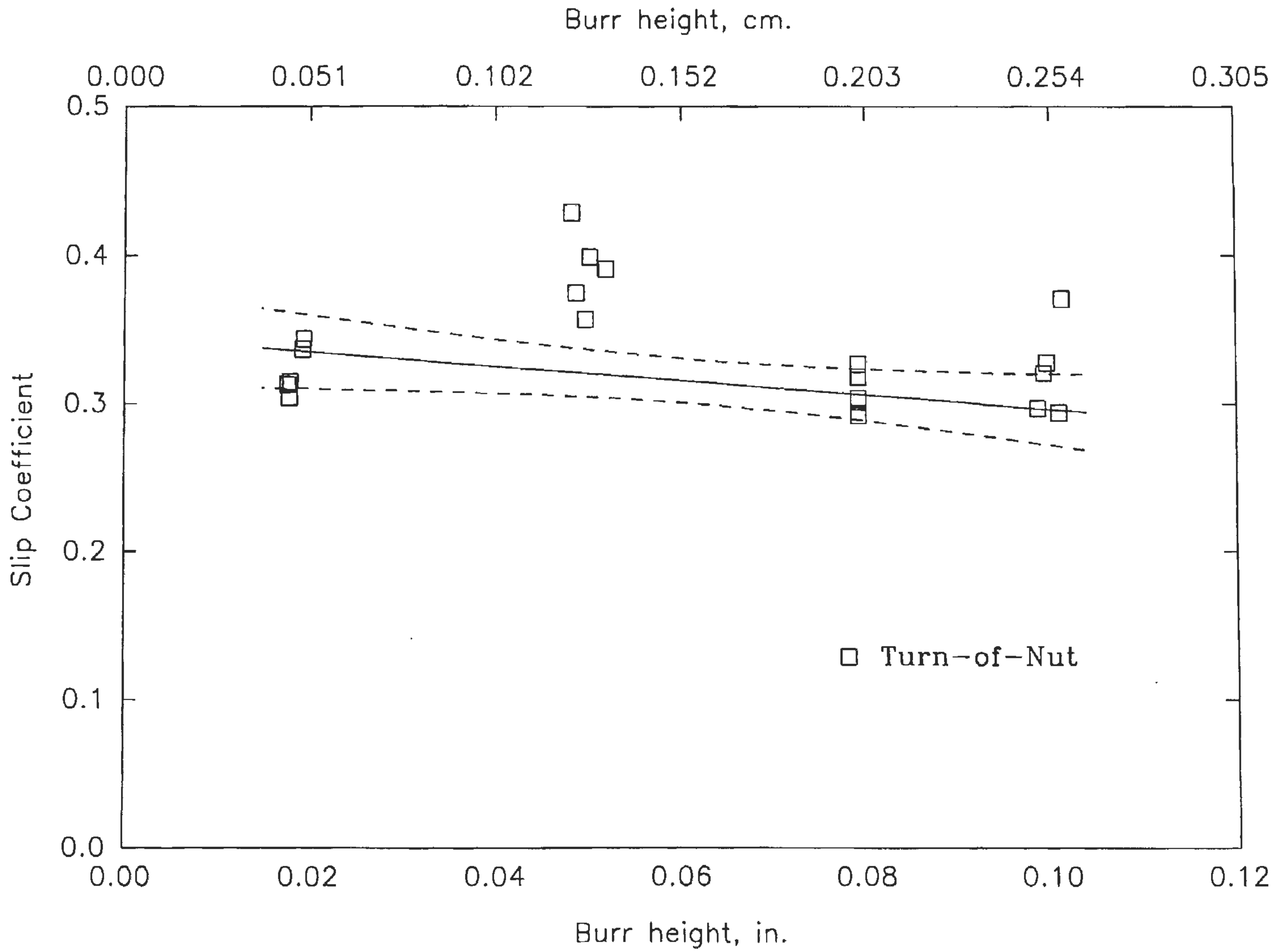


Figure 19. Slip Coefficient Versus Burr Height for Turn-of-Nut Data
With 99% Confidence Limits for All Data

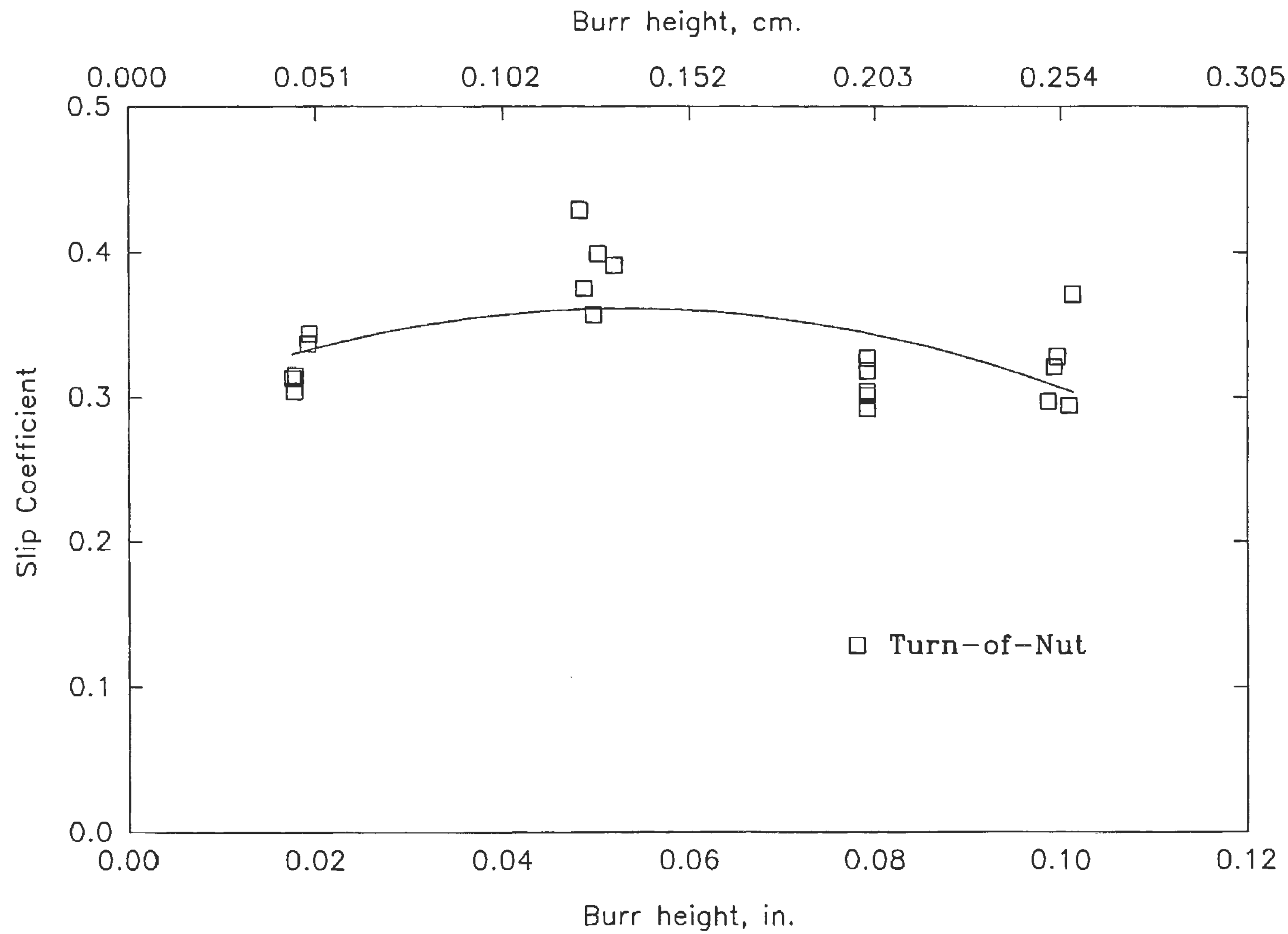


Figure 20. Slip Coefficient Versus Burr Height for Turn-of-Nut Data
With Second-Order Regression

and then the splined end twisted off before another 1/4 turn was complete. All five had tensions between 32 and 33 kips, with an average of 32.5 kips. Turn-of-nut tightening ceased when all four bolts had a minimum tension of 28 kips. This difference in bolt tension accounts for the approximate extra 1/4 turn required for tension control.

TABLE 3

AVERAGE NUMBER OF TURNS REQUIRED
FOR MINIMUM BOLT TENSION, 28 KIPS

Average Burr Size, in.	Tension Control	Load Indicating Washer	Turn-of-Nut
0.0177	0.4875	0.60	0.25
0.0496	1.0375	1.05	0.75
0.0792	1.3750	1.15	0.95
0.0993	1.4500	1.35	1.05

The higher initial tension in tension control bolts is lowered when other bolts in the connection are tightened, which leads to slightly lower slip coefficients, as described previously. This study indicates that the tension control method reliably achieves bolt tension if a repetitive tightening sequence is followed using small, even turning increments.

Load indicating washer tightening also required more rotation than turn-of-nut. This is due to the direct tension indicators acting like burrs. Additional rotation is required to flatten the direct tension indicators, as well as the actual burrs, before plate surfaces come into contact. Further rotation causes the bolts to become properly tensioned. The load indicating washer method also reliably achieves bolt tension if a repetitive tightening sequence is followed, using small, even turning increments.

The turn-of-nut method required the fewest rotations, regardless of burr size. However, the required rotation depends on burr size. Because the number of rotations depends on burr size and there is no direct means to determine bolt tension, the turn-of-nut method cannot reliably achieve bolt tension in multiple bolt connections with burrs.

Polyzois and Yura [8] recommend using Table 5 of Section 8 of the RCSC's "Specification for Structural Joints Using ASTM A325 or A490 Bolts" to determine the required nut rotation for plates with burrs. They recommend using the column in the table for conditions when both faces of the bolted parts are sloped not more than 1:20 from normal to the bolt axis. According to this recommendation, 2/3 of a full rotation from snug tight conditions is required to fully tension bolts of the length and diameter used in this study. Table 3 of this study shows that this rotation would not produce full tension with burrs as small as 1/32 in. This study indicates that using the RCSC specification to determine the number of turns for multiple bolt connections with burrs would not reliably achieve bolt tension.

Figure 21 shows the variation in final bolt tension with tightening sequence. First-order regression lines for the load indicating washer and the turn-of-nut methods are shown. Tension control is not represented because the tension cannot be measured. Bolt 1 was tightened first and bolt 4 was tightened last. The graph shows an increase in tension of approximately 1 kip from bolt 1 to bolt 4.

There is a larger difference in tension between bolts when tightening begins. This is due to bolts being tensioned and then relaxing as other bolts are tightened. After burrs are flattened, the bolts no longer relax when others are tightened. This allows final bolt tension to be approximately the same as shown in Figure 21. It is not apparent why turn-of-nut tension is higher than that of load indicating washer.

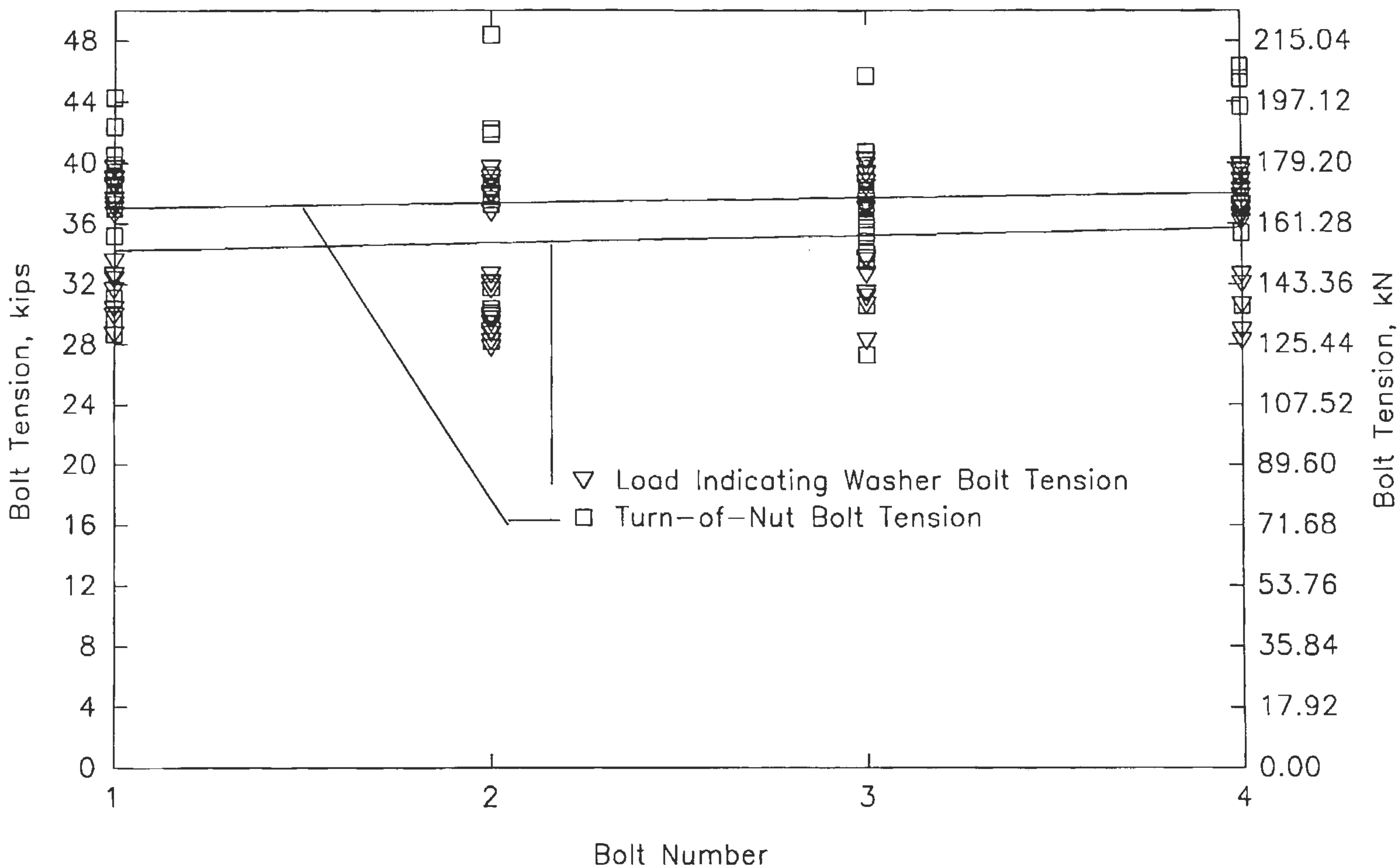


Figure 21. Bolt Tension Versus Bolt Number

Figure 22 is a histogram of bolt tension in the load indicating washer and turn-of-nut specimens. The histogram shows that nearly all bolts had higher tensions than the 28-kip minimum. This is because if one or more bolts in a specimen had a tension below 28 kips, all four bolts were tightened another 1/4 turn.

Kulak and Birkemore [5] found that the average tension in field-installed A325 bolts was 1.21 times the minimum specified tension. The standard deviation was 0.05 of the minimum specified tension. Applying these numbers to the minimum tension in the present study, 28 kips, results in a mean tension of 33.9 kips and a standard deviation of 1.4 kips. These are lower than the values of all bolts in the present study. The mean is 35.9 kips and the standard deviation is 3.6 kips. This is because all bolts were turned if one or more were below the minimum, as stated previously.

Kulak, Fisher, and Struik [4] found that A325 bolts tightened 1/2 turn from snug had a mean bolt tension of 1.20 times the minimum required tension. Standard deviation was 0.09 of the minimum. Applying these values to 28 kips results in a mean tension of 33.6 kips and a standard deviation of 2.5 kips. These figures are lower than the turn-of-nut figures in the present study, 37.6 and 3.9 kips.

Reference [4] also contains tension control data courtesy of suppliers. The average bolt tension data from three suppliers resulted in 1.22 times the minimum bolt tension with a standard deviation of 0.1. Applying these numbers to the present study results in a mean tension of 34.2 kips and a standard deviation of 2.8 kips. Five tension control bolts were tested in this study and the average tension used for all tension control bolts. This average was 32.5 kips with a standard deviation of 0.5 kips.

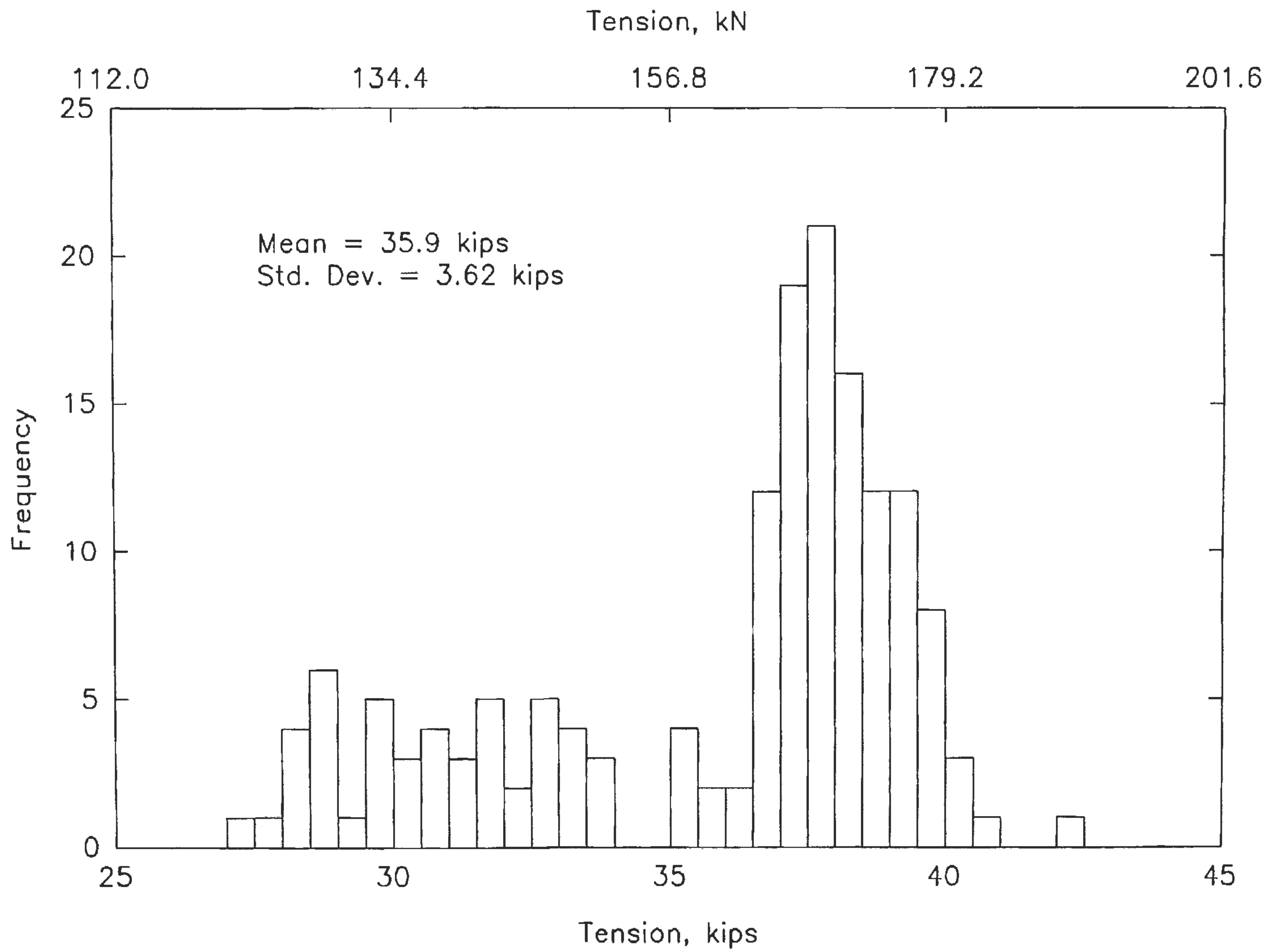


Figure 22. Histogram of Tension in Load Indicating Washer and Turn-of-Nut Bolts

CHAPTER IV

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

4.1 Summary

Tests have been conducted to assess the effect of burrs on shear capacity of slip-critical connections. The connections were constructed from four 3/4-in. diameter A325 bolts and A572 Grade 50 steel plate. Bolts in the slip-critical connections were tightened using tension control, load indicating washer, and turn-of-nut methods. All faying surfaces were clean mill scale.

The purpose of this study was to determine if burrs reduce capacity in slip-critical connections. To accomplish this purpose the variation of slip coefficient with burr height was examined. This study was not conducted to supplement available data on slip coefficients for clean mill scale surfaces. Conclusions are based on comparisons of slip coefficient between burr heights, not on comparisons to published data for clean mill scale specimens.

4.2 Conclusions

On the basis of the research described in this report, the following conclusions are drawn:

1. Slip coefficients tend to increase in multiple bolt connections as burr height increases from 0 to 1/16 in., and then slowly decrease as burr height increases beyond 1/16 in.
2. If burrs are present in a multiple bolt connection, bolt tension cannot be reliably achieved using turn-of-nut methods. Tension control bolts and load

indicating washer methods can be used to reliably achieve bolt tension, if a repetitive tightening sequence is used with small even turning increments.

3. The last bolts to be tightened in a tightening sequence have higher bolt tension, but the difference between bolts is small.

4.3 Recommendations

1. In Section 3(b) of the RCSC Specification, the sentence "Burrs that would prevent solid seating of the connected parts in the snug tight condition shall be removed" should be replaced by "Burrs extending 1/16 in. or less above the plate surface are permitted. Larger burrs shall be removed."
2. In Section 8(c) of the RCSC Specification, the sentence "The snug tight condition is defined as the tightness that exists when all plies in a joint are in firm contact" should be deleted. This recommendation is supported by the Commentary to Section 8(c) of the RCSC Specification.

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VITA 2

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